Research article

Non-uniform Distribution of Soil Salinity Along a Transect of an Irrigation Field in an Arid Region

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Abstract We assessed soil salinity at field scale and suggested appropriate water and salt management practices for an arid region. Specifically, we focused on non-uniform salinity distribution along a transect in a research field. We also examined factors affecting the distribution of salt, including irrigation, drainage and salt movement. The non-uniform salinity distribution across the field was probably formed by irrigation management and distance from main drainage channel, while the effect of soil physical properties and groundwater was limited. The main drainage channel functioned well during the past irrigation period when abundant *Karez* water was available for leaching irrigation, and this contributed to the present non-uniform salinity distribution. Currently, farmers use less irrigation water, which does not promote desalinization. Vertical movement of soluble salts near the soil surface was dominated by irrigation management. Border irrigation promotes desalinization but drip irrigation enhances salt accumulation, with salinity increasing after irrigation because of high evaporation rates in the hyperarid climate. Based on these results, we explained the following points to local farmers in non-technical language: 1) a drainage channel is important for desalinization but the current channel is no longer sufficient to discharge salt from the field; 2) drip irrigation is effective for deficit irrigation but it enhances salt accumulation; 3) border irrigation has a positive effect on salt leaching from surface layers but the leached salt returns to the surface after irrigation ceases; and 4) there are high salinity layers below 60 cm soil depth, distributed widely across the fields.

Keywords drainage, hyperarid region, irrigation, non-uniform distribution, soil salinity

INTRODUCTION

It is estimated that saline soil covers 3.1% (397 mega hectares) of the total land area of the earth (FAO, 2005), which is 1.2 times larger than the land area of India. The total area of secondary saline soil induced by anthropogenic activity such as agriculture is approximately 76.6 Mha (Oldeman et al., 1991), almost twice of the land area of Japan. There are no data to suggest that the amount of saline soil is decreasing; on the contrary, Rengasamy (2008) expects that the prevalence of saline soil will increase because of climate change and increasing human population.

Salinization is one of the biggest problems affecting agricultural activities, especially in arid regions. Salinity studies have been conducted since the 1950s. Soil electrical conductivity (EC) has long been used as an index of salinity in the laboratory (US Salinity Laboratory Staff, 1954), though electromagnetic induction (McNeill, 1980; Rhodes and Corwin, 1981) and satellite remote sensing (Metternicht, 2003; Metternicht and Zinck, 2008) are now widely applied to assess the extent and severity of saline areas. Free numerical modeling software (e.g., Šimůnek et al., 2013) is available for simulating the movement of water and salt in soil layers.

In irrigated agricultural fields, non-uniform distribution of soil salinity is caused by inappropriate application of water and salt management practices such as irrigation, drainage and salt leaching (Kume et al., 2004; Nishimura et al., 2012). This leads to loss of irrigation water and decreasing crop production. Knowledge of the structure of the non-uniform distribution, and available technical solutions, is crucial to effective management of water and salt in arid regions. However, field conditions and irrigation techniques differ from one place to another, and so a site-specific approach is needed to help farmers to understand their current situation and to suggest ways of developing saline soil in an appropriate way.

OBJECTIVE

We assessed soil salinity at field scale and suggested appropriate water and salt management practices for an arid region. Specifically, we focused on non-uniform salinity distribution along a transect in a research field. We also examined factors affecting the distribution of salt, including irrigation, drainage and salt movement.

METHODOLOGY

Research Field

The research field is situated in Paran Karez village near the city of Torpan, in the Xinjiang Uygur Autonomous Region of China (Fig. 1). The average temperature at Torpan is 14.0 °C. Maximum and minimum temperatures are 40 °C and −14.5 °C, respectively. Annual precipitation is 16.6 mm. Torpan is classified as a hyperarid region.

Fig. 1 Location of Torpan in the Xinjiang Uygur Autonomous Region, China

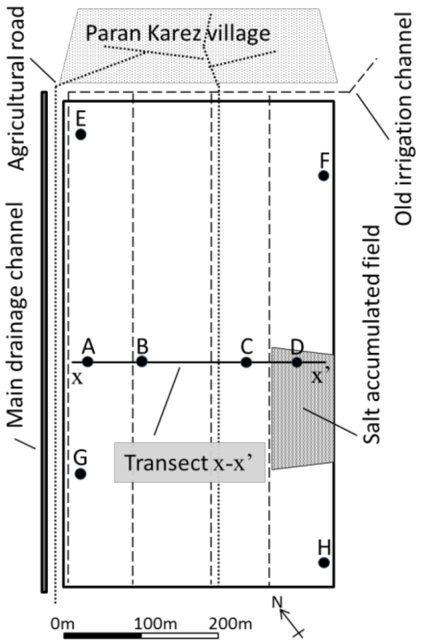

Fig. 2 Map of investigation area, showing transect x-x', soil profile sampling points (A-D), and reference soil sampling points (E-H)

The village of Paran Karez has been developed using water from Paran Karez over the last 300 years. The term *Karez* means a horizontal series of vertically dug wells that are then linked by underground water canals. Unfortunately, Paran Karez dried up in 2010. Farmers irrigated their fields with Paran Karez groundwater 20 years ago and now they pump up groundwater from wells for irrigation. The main crops grown are cotton, maize, wheat and cumin. The most common irrigation methods are basin irrigation and border irrigation; drip irrigation has been introduced in some areas beginning in 2013.

Materials and Methods

We defined a transect, x-x', in the irrigated field (Fig. 2) to reveal horizontal soil salinity distribution and took soil samples at 10 meter intervals in June 2013, October 2013, May 2014 and November 2014. Soil samples were taken from 0–5 cm and 5–15 cm below the soil surface. Soil electrical conductivity was measured in a soil-water extract (soil:water = 1:5, $EC_{1:5}$). To examine the topography of the transect, we conducted a level survey at 50 meter intervals in May 2014. To examine the vertical profiles of soil salinity and soil physical properties, we also took soil samples at four points, A, B, C and D on the transect at six soil depths from each profile wall: 0–5, 5–15, 15–30, 30–60, 60–90 and 90–120 cm below the soil surface. The same sampling and measurement regime was used at four reference points, E, F, G and H, some distance away from the transect.

RESULTS AND DISCUSSION

Soil Physical Properties

Soil physical properties affect water and salt movement in soils. Therefore, soil physical properties were examined to understand non-uniform distributions of soil salinity in irrigated fields. The soil texture was classified as International Society of Soil Science at the four points along the transect (A to D) was silty loam (SL) as shown in Table 1. The soil was mainly composed of silt and it contained less than 10% clay. The same silty loam texture was seen at the reference points (E to H). Soil bulk density showed that the soils were somewhat compacted, and soil permeability was reduced, ranging from 10^{-5} to 10^{-6} cm/s^{-1}. Particle density ranged from 2.64 to 2.76 g/cm^{-3}, indicating low organic matter content. From these results, we expect that the differences of soil physical properties were not so large that it did not affect non-uniform distribution of the soil EC.

Table 1 Average values of physical properties of soil from 0-1.2 m soil depth at points A-D along the transect x-x'

Point	Soil texture	Soil bulk density (g/cm^3)	Particle density (g/cm^3)	Soil permeability (cm/s)
A	SL	1.27	2.64	1.8×10^{-5}
B	SL	1.31	2.76	1.8×10^{-6}
C	SL	1.35	2.74	1.8×10^{-6}
D	SL	1.27	2.76	3.6×10^{-6}

Effect of Irrigation Methods on Surface Soil Salinity

Irrigation practices affect water and salt movement, especially salt leaching at the soil surface. As shown in Table 2, the average value of $EC_{1:5}$ for all data including non-irrigated fields, and $EC_{1:5}$ excluding non-irrigated fields ranged from 4.8 to 7.6 dS/m and from 2.2 to 3.5 dS/m, respectively. The highest $EC_{1:5}$ values were observed in non-irrigated fields 280-300 m away from the main drainage channel along the transect (Fig. 2), whereas the lowest $EC_{1:5}$ values were obtained near the main drainage channel. $EC_{1:5}$ was high in the non-irrigated fields because of the lack of salt leaching without irrigation, and salt accumulation from the vicinity by lateral water flow. It is clear that irrigation and drainage management affects surface soil salinity.

Changes in average $EC_{1:5}$ during the research period (Table 2) can be interpreted in the light of irrigation management practices and salt movement. First, border irrigation leached surface salt to the deeper soil layers (June 2013), and the leached salt was returned to the soil surface by evaporation (October 2013). Second, drip irrigation induced intense capillary rise and promoted salt movement from deeper layers to the surface (May 2014) (Zhang et al., 2014). Finally, salt continuously rose to the soil surface by evaporation and showed the highest $EC_{1:5}$ at the end of the research period (November 2014). This shows that border irrigation promotes leaching of salt to deeper soil layers, while drip irrigation enhances salt mobility from deeper soil layers to the surface.

Table 2 Descriptive statistics for $EC_{1:5}$ at four measurement times

Data used for statistical analysis	Sampling date (Month/Year)	Irrigation	Soil $EC_{1:5}$ (dS/m)			
			Mean	Max	Min	Standard deviation
N=31 (0-300 m) (Including data from salt accumulate fields, 280-300 m from drainage channel)	06/2013	Border irrigation	4.8	47.8	0.5	9.3
	10/2013	-	5.8	59.6	0.2	11.5
	05/2014	Drip irrigation	7.6	84.5	1.5	15.0
	11/2014	-	6.9	41.2	0.4	9.4
N=28 (0-270 m) (Irrigated fields only)	06/2013	Border irrigation	2.2	5.4	0.5	1.1
	10/2013	-	2.7	6.3	0.2	1.6
	05/2014	Drip irrigation	3.4	8.5	1.5	1.7
	11 2014	-	3.5	8.9	0.4	1.9

Relationship Between Soil Salinity and Distance from Main Drainage Channel

The salt distribution before agricultural development of the research field was not known. However, conventional desalinization using techniques such as leaching irrigation has been employed since the 1970s, so it is unsurprising that soil salinity increases with increasing distance from the main drainage channel (Fig. 3). The only exception was seen in May 2014. Regression analysis showed a positive correlation between $EC_{1:5}$ and distance from main drainage channel (Fig. 3). The highest coefficient of determination (R^2), 0.71, was obtained in October 2013 and the lowest, 0.22, was seen in May 2014. Similar results were obtained across the irrigated field, from 0 to 270 m from the drainage channel along the transect x-x'. This relationship was not seen in May 2014 and the R^2 value at that time was just 0.02 (data not shown). Conventional desalinization management with abundant *Karez* water in the past promoted leaching and salt drainage from soil layers. This is consistent with the $EC_{1:5}$ data from May 2014, which showed that drip irrigation temporarily caused a uniform salinity distribution through intense capillary rise in the irrigated field.

The topographic level survey showed that the elevation became higher with increasing distance from the main drainage channel (Fig. 3). Non-irrigated salt accumulated fields, which were located 280–300 m away from the drainage channel, were higher than the irrigated fields. This implies that salt accumulated fields have not been received enough leaching water because of their higher elevation, and that dissolved salt moved from nearby fields. The same results were seen by Kume et al., (2004) and Nishimura et al., (2012).

Distribution of Salinity Profile

Desalinization practice involves a series of leaching and draining salt from soil layers to the drainage channel. We assessed the salinity profile in the root zone and below to develop an effective desalinization strategy. Results showed two types of salinity profile as shown in Fig. 4. At point A, which was the nearest point to the drainage channel, soil salinity was observed to increase with depth. In contrast, at points B, C and D, salinity decreased with depth below the soil surface. Salinity of soil from 0 to 40 cm deep increased with distance from the drainage channel, this trend was similar to the results shown in Fig. 3.

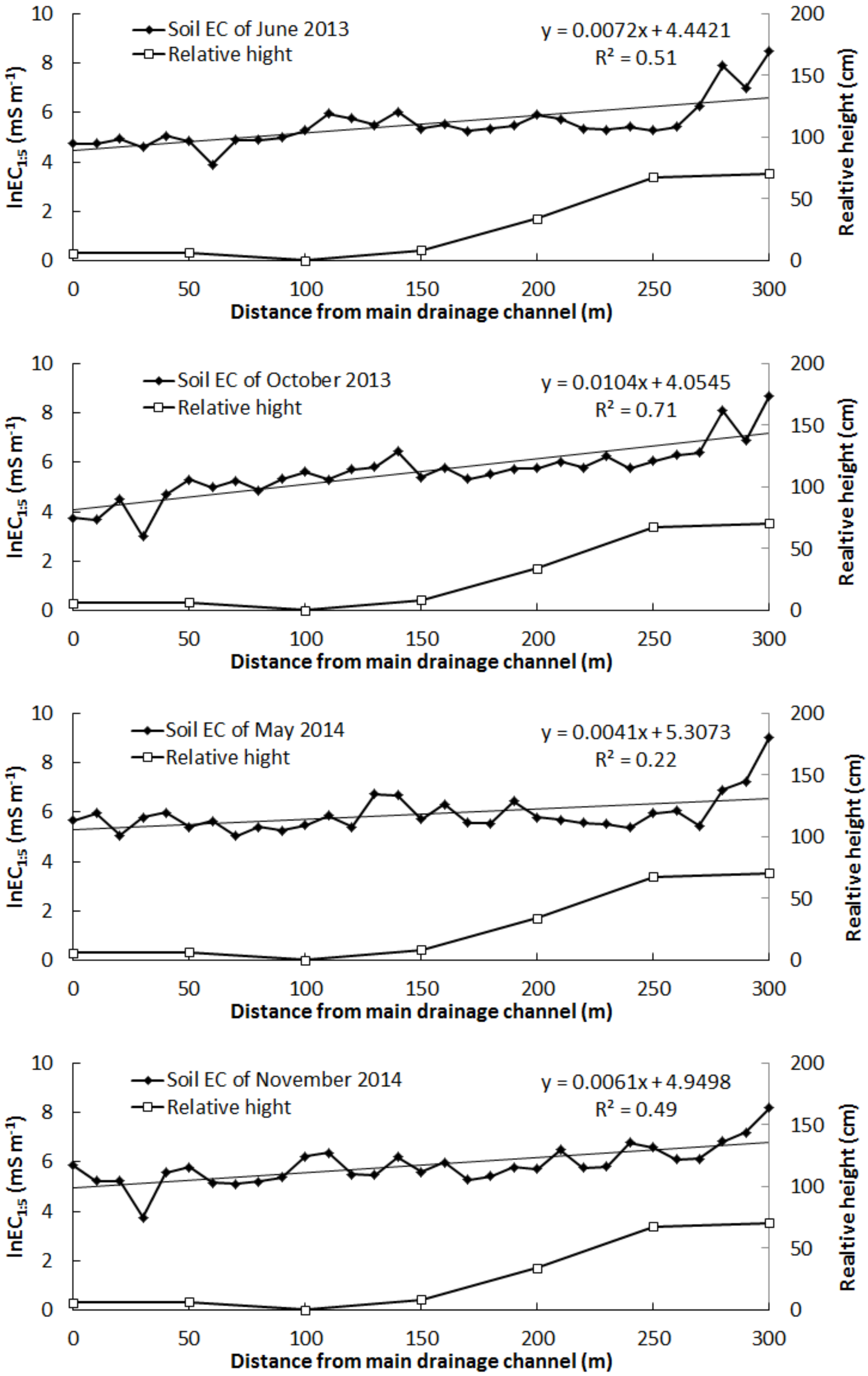

Fig. 3 Changes in spatial distribution of $EC_{1:5}$ along the transect x-x' at four measurement times and relative height of the transect

High salinity layers (2.0–2.5 dS/m) were found at around 60 cm soil depth at points A, B and C (and also at E, F, G and H, reference points (data not shown)). This indicates that high salinity layers below 60 cm soil depth are widely distributed across the fields. Based on our field survey, it was confirmed that groundwater depth was at least 4.0 m below the soil surface, so the effect of groundwater on the salinity profile was negligible during the observation period.

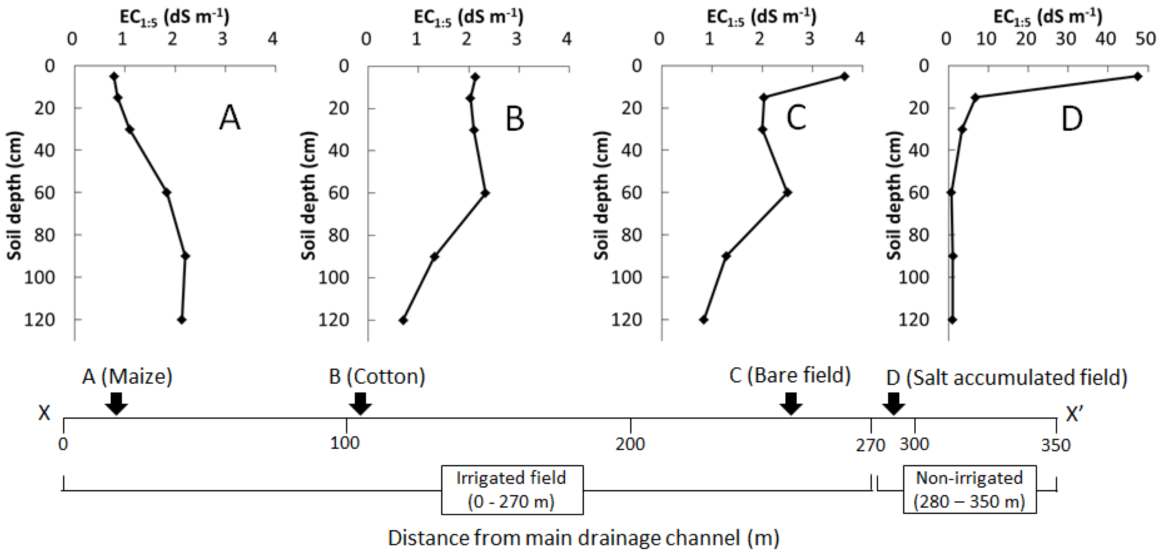

Fig. 4 $EC_{1:5}$ of soil vertical profiles at points A to D along the transect and distribution of crops cultivated in June 2013

Structure of Non-Uniform Salinity Distribution of the Field

The non-uniform salinity distribution across the field was probably formed by irrigation management and distance from main drainage channel, while the effect of soil physical properties and groundwater was quite limited. The main drainage channel functioned well during the past irrigation period when abundant *Karez* water was available for leaching irrigation, and this contributed to the present non-uniform salinity distribution. Currently, farmers use less irrigation water, which does not promote desalinization. Vertical movement of soluble salts near the soil surface was dominated by irrigation management. Border irrigation promotes desalinization but drip irrigation enhances salt accumulation, with salinity increasing after irrigation because of high evaporation rates in the hyperarid climate.

CONCLUSION

In this study, we identified the primary factors affecting structure of non-uniform salinity distribution in terms of irrigation and drainage management. Based on these results, we will explain the following points to local farmers in non-technical language: 1) a drainage channel is important for desalinization but the current channel is no longer sufficient to discharge salt from the field; 2) drip irrigation is effective for deficit irrigation but it enhances salt accumulation; 3) border irrigation has a positive effect on salt leaching from surface layers but the leached salt returns to the surface after irrigation ceases; and 4) there are high salinity layers below 60 cm soil depth, distributed widely across the fields.

Two-dimensional profiles of salt and water distribution and their movement within and between soil layers are required to manage agricultural activity in the research area. We plan to simulate salt and water balance using a numerical model assuming installation of various types of drainage channels and adoption of different irrigation managements to develop a practical strategy for irrigation and drainage management for local farmers to employ in the research field.

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REFERENCES

FAO. 2005. Global network on integrated soil management for sustainable use of salt-affected soils. Rome, Italy: FAO Land and Plant Nutrition Management Service.

Kume, T., Nagano, T., Watanabe, T. and Mitsuno, T. 2004. Analysis of heterogeneous soil salinity distribution in poor drainage Field. Trans. of JSIDRE, 234, 19-26. (In Japanese with English abstract)

McNeill, J.D. 1980. Electromagnetic terrain conductivity measurement at low induction numbers. Mississauga, Ontario, Canada, Geonics Limited, Technical Note TN-6.

Metternicht, G.I. 2003. Categorical fuzziness: A comparison between crisp and fuzzy class boundary modeling for mapping salt-affected soils using Landsat TM data and a classification based on anion ratios. Ecological Modelling, 168, 371-389.

Metternicht, G.I. and Zinck, A. 2008. Remote sensing of soil salinization: Impact on land management. CRC Press.

Nishimura, T., Ishiyama, Y., Seki K., Imoto, H.， Mizoguchi, M. and Miyazaki, T. 2012. Salt accumulation above shallow ground water table at Songnen Plain, Heilongjian, China. IDRE Journal, 279, 35-44. (In Japanese with English abstract)

Oldeman, L.R., van Engelen, V.W.P. and Pulles, J.H.M. 1991. The extent of human-induced soil degradation. World map of the status of human-induced soil degradation: An explanatory note. Wageningen: International Soil Reference and Information Center, 27-33.

Rengasamy, P. 2008. Salinity in the landscape: A growing problem in Australia. Geotimes, 53, 34-9.

Rhodes, J.D. and Corwin, D.L. 1981. Determining soil electrical conductivity-depth relations using an Inductive electromagnetic soil conductivity meter. SSSAJ, 45, 255-260.

Šimůnek, J., Šejna, M., Saito, H., Sakai, M. and M. Th. van Genuchten. 2013. The Hydrus-1D software package for simulating the movement of water, heat, and multiple solutes in variably saturated media, Version 4.17, HYDRUS Software Series 3. Department of Environmental Sciences, University of California Riverside, Riverside, California, USA.

US Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. USDA Handbook, No. 60, Washington, D.C, US Government Printing Office, USA.

Zhi, Z., Hongchang, H., Fuqiang, T., Heping, H., Xinhua, Y. and Ruisen, Z. 2014. Soil salt distribution under mulched drip irrigation in an arid area of northwestern China. Journal of Arid Environments, 104, 23-33.